Medical Informatics
and
Telemedicine
for
Space Flight

Report on Strategic Planning Workshop
Conducted
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Executive Summary

Participants in the Medical Informatics and Telemedicine for Space Fight workshop were asked to make recommendations regarding NASA's future medical informatics and telemedicine efforts in support of International Space Station (ISS) and Exploration Class Missions. The early part of the workshop was devoted to a number of presentations from NASA representatives and participants about important efforts in the field. The workshop participants participated in a number of the group activities, exercises, resulting in a number of important recommendations.

The workshop participants addressed NASA's strategic vision, requirements, approach, and made a recommendation regarding the "architecture" of space medical practice. In general, the participants recommended that space travelers be empowered through the use of medical informatics technologies to successfully address medical issues and to achieve acceptable clinical outcomes. The highest quality medical and surgical care for astronauts may only be provided through the integration of medical information technologies. NASA should recognize that the field of medical informatics would form the overall architecture of space medicine in the future. The adoption of the "medical informatics architecture" concept by NASA will dictate important changes in space medicine practice paradigms, medical support systems, and require a new approach to the training of physicians and others who are responsible for health care.

There was some discussion by the participants of their understanding of the terms medical informatics and telemedicine. The term telemedicine has traditionally been used to describe a medical practice paradigm in which the patient and health care provider are separated and health care is provided, at least in part, through the use of television and/or other communications capabilities. Since the introduction of the personal computer along with the recent development of the Internet, there have been changes in our concept of practicing medicine at a distance. Increasing reliance by health care providers on an evidentiary basis for their diagnostic and treatment approaches further alters the traditional approach to health care and has significant implications for the future of health care in space, whether supported by communications with Earth or not. Given the perceived weakness of the term telemedicine to adequately address even a small part of the health care paradigm that future space medicine health care providers will rely on, the participants recommended that NASA adopt the term medical informatics.

As chairman of the medical informatics and telemedicine workshop, I was very pleased with the level of participation and with the recommendations that emerged from the deliberations. The conclusions of the workshop may be somewhat unsettling to some working in the field. It is very important to observe that some recommendations would require a significant reprioritization of current NASA efforts in medical informatics and telemedicine.

Sam L. Pool, M.D.

Introduction

The focus of your workshop should be the application of telemedicine to space flight. NASA was one of the first organizations to apply telemedicine. The Mercury astronauts were monitored using a miniaturized electrocardiograph system. Current NASA efforts to apply telemedicine to space flight are not robust. It is with this fact in mind that we have asked you to work with us to define a new strategic vision for NASA in the field of telemedicine.

Telemedicine is emerging as an important tool in medical care. This applies particularly to primary care and emergency care in remote areas. NASA efforts to develop a telemedicine capability for the Shuttle have included the provision of an advanced cardiac life support system (ACLS) on Neurolab and STS 90. Primary medical care on the International Space Station (ISS) is provided by the Crew Health Care System (CHeCS). NASA has developed the Telemedicine Instrumentation Pack (TIP), which is a computer based system that can video image the eye, ear, nose, throat, and skin. The TIP may be used to monitor the EKG, Sp02, blood pressure, and heart rate. An electronic stethoscope is included. The TIP is designed to interface with Shuttle and ISS Ku-Band communications capability. The TIP may be of use in the early phase of the ISS operations, but it is considered inadequate for the mature operational phase of the ISS and for exploration class missions. The TIP has flown once on the Space Shuttle but it is not routinely flown.

Currently access to NASA medical consultants in conjunction with space flight relies heavily upon on the telephone and electronic mail. In the future we anticipate more reliance on the application of telemedicine to our consultant capability.

The use of telemedicine for medical education in support of space flight is almost nonexistent. Educating medical personnel in the use of telemedicine is likewise in its earliest stages of discipline development and not applied as a mater of routine by NASA. Education of medical care providers in the use of telemedicine and the use of telemedicine for medical education in support of space flight must be addressed.

There are many opportunities to apply telemedicine on space station. Every thirty days astronauts will complete an in-flight physical examination in order to assess the effects of various countermeasures to the deconditioning effects of space flight. Perhaps there are innovative ways to apply telemedicine to monitoring these examinations. Should we be developing more sophisticated noninvasive sensors and building including those sensors in the EVA suit? Should we be developing "smart sensors" to monitor various body parameters and functions? We used a core temperature monitor on STS 90. Should we restructure the TIP for use on ISS? Should we include an ACLS capability as a part of a telemedicine system for ISS mature operations? Should we go so far as to have automatic equipment and standing orders, protocols, and algorithms? What should the next generation NASA telemedicine system resemble? Should it be like the TIP, should it be a distributed System? Perhaps it should be modeled after the Doc in the Box developed by MIT?

Does telemedicine have a role in laparoscopic diagnosis and surgery in space? Can telemedicine be used to provide part of a virtual environment for laparoscopic diagnosis and surgery in space? On STS-90 animal surgery was done without any serious problems due to the fact that it was being done in microgravity. Will wound healing be a problem? Can telemedicine be employed to assist in post surgical monitoring? As you can see there are many questions.

Telemedicine may be used to provide medical consultation. On International Space Station the health provider may choose to call Mission Control and consult with the flight surgeon. The Mission Control flight surgeon, in turn, may wish to consult with someone from the academic community. Better methods of communication and data sharing should be considered.

Telemedicine and Medical Informatics may play a very important role in education. Consider a space crew on a three-year mission. Recurrent medical training will be very important. How do you maintain medical and surgical skills on a very long mission in space? On STS-90 one of the experiments required very delicate surgery to place electrodes in the hippocampus of a rodent to record waveforms. The mission specialists on STS-90 were not electrophysiologists so a real-time downlink was used for consultation. This approach worked. If this kind of approach works for telescience, it should be useful for medicine in certain instances.

Significant signal delays associated with some missions in space will be an important factor to consider. In many cases "store and forward" may be useful. Fully automatic and autonomous approaches may be best for some tasks such as advanced cardiac life support. Surgery presents some unique issues in space. Initial training may be accomplished before the mission; however, maintenance of skills will be a significant issue. Can telemedicine and/or medical informatics fill this need? Can we anticipate the changes in technology that may be of significant use?

This workshop represents an important step in reorienting NASA's approach to the application of Medical Informatics to Space Medicine. We need to use all our assets to assist in this arena. Consider what contributions the ISS international partners, National Space Biomedical Research Institute, Department of Defense, Medical Informatics and Technology Applications Consortium, may make, as well as NASA.

David Williams, M.D.

Charge to the Workshop

NASA has a longstanding interest in telemedicine. The Mercury astronauts were monitored from ground stations via telemetry using one of the world's first miniaturized electrocardiographs in conjunction with NASA's space communications network. Monitoring the Mercury astronauts from ground stations using telemetry fits the general definition of telemedicine; however, is also true that television was not used in the space program until later. When I was first introduced to the term telemedicine I thought it meant the application of telemetry to the transmission of medical data. As the interest in the application of television technology to the care of a patient in a remote location began to develop NASA became interested in the development of telemedicine for application in support of human space flights.

In 1969 NASA undertook the development of a telemedicine system for application in a terrestrial setting. In part, this NASA telemedicine effort was to serve as a demonstration of revenant NASA technology developments to the public sphere and in part, to assess the technology for application to space. This effort culminated in a cooperative program with the Indian Health Service and the Papago Indian tribe to enhance access to health care on the Papago reservation.

The NASA investment in the development of space medicine is very small as compared to the investment made by the Agency in biomedical research and countermeasures. In part, this is due to the fact that short exposures to microgravity by a few very carefully selected astronauts has not resulted in a number of openly reported life threatening medical problems during short space flights. According to some, the absence of open reported life threatening medical problems to date in space program implies that there is little need to be concerned about health related issues on long International Space Station flights or on exploration class missions. Our U.S. Mir experience gained through a series of three- to four-month Mir missions indicates serious concern regarding medical care and physiological and psychological aspects of long duration missions.

Modifying Earth-based models of evidence-based medicine for clinical care in space is not a simple process. We do not have sufficient understanding of human adaptation to microgravity to be certain that our medical interventions will be successful. There are many clinical unknowns. Clinical research is required to enable practitioners of space medicine to conduct their practice with an evidence base. The development of space medicine must address the classical clinical medicine triad of prevention, diagnosis, and treatment in microgravity as well as development certification of clinical equipment that will function in the space environment. Appropriate skills be identified for those who will deliver health care in space, and they must be trained in the field of space medicine.

The definition of the term "telemedicine" is apparently still evolving. Early telemedicine definitions stressed heavily the application television to the delivery of health care. More modern definitions of telemedicine tend to stress providing health care to patients at a distance using modern communications and data capabilities emerging via use of the Internet. The modern telemedicine concept embodies the robust capability to exchange many forms of medical data including innovative ways to handle images.

The future practice of medicine may rely heavily on the ability of health care providers to handle all forms of medical data in what today would be considered very novel ways. The term telemedicine does not seem to gracefully adapt to new paradigms for medical practice on Earth or in space. A term that seems to be gaining in popularity, "medical informatics," is emerging and is in apparent competition with the term telemedicine. Medical informatics may be the best term to use to address the future paradigm for medical practice on Earth as well as in space.

The workshop participants were urged not to allow the use of the term telemedicine in the title for this workshop limit deliberations with regard to NASA's strategic plan in this area. Rather, they were asked to pay particular attention to NASA's requirements for the application of medical informatics and telemedicine to those space missions NASA refers to as exploration class missions. In the near term the application of a telemedicine to the International Space Station (ISS) is rather limited. In the long term, the ISS should be an important arena for testing and verification of new systems for the delivery of health care in space.

Sam Lee Pool, M.D.

Comments, Recommendations, and Findings

Working Group response to group activities, exercises

For each of the following four exercises, the Working Group was divided into three subgroups. The three subgroups reported their comments, findings, and recommendations to the Working Group.

Exercise 1: Develop Vision ***(Sam L. Pool, M.D., facilitator)***

The first exercise tasked the subgroups to develop vision statements for NASA to consider in the pursuit of the development of medical informatics and telemedicine for support of space flight. Each of the three groups developed vision statements for NASA. They addressed the development of medical informatics and telemedicine technologies for applications to the provision of health care to space travelers. The groups supported the idea that medical informatics is a better term to apply to NASA's effort in this area than telemedicine.

Subgroup A.

Empower the crew to achieve acceptable clinical outcomes, through the use of advanced technology and through developing an innovative model of care. Desired outcomes will be determined by risk assessment of the overall mission and oriented toward maximizing mission success.

Subgroup B.

Require, develop, and apply medical informatics to support and manage evidence-based medical practice in space, optimally independent of distance and time. The process and implementation will be collaborative and reflective as health care in general and the NASA mission evolve.

Subgroup C.

Provide the highest quality of health care for our astronauts through the integration of medical and information technologies to maintain skills, knowledge, safety and readiness to maximize mission impact. Provide health care supporting human exploration and the development of space enterprise that meets or exceeds terrestrial standards of care.

__Exercise 2: Define Requirements (James Logan, M.D., facilitator)__

The subgroups focused on the requirements to support the vision they had enunciated in Exercise 1. They were to focus particularly on the long-term needs of NASA in the area of medical informatics and telemedicine.

<u>Subgroup A.</u>

Medical capabilities that are required and that must be available on the space ship.

A. Health optimization, Wellness
B. Crew selection medical screening, preflight
C. Diagnostics
D. Interventions

These four requirements are addressed in the following:

A. Health optimization, Wellness

1. Physical
    a. Environmental
    b. Nutrition
    c. Sleeping, (appropriate work and rest cycles)
    d. Exercise
    e. Disease prevention

2. Psychosocial
    a. Psychological
    b. Motivation
    c. Recreation

B. Screening

1. Crew selection (pre-launch)
2. Risk profile (pre-launch)
3. Subclinical disease
    a. Routine physical and psychological assessment
4. Public health/ Epidemiologic

Address and analyze pre flight factors. As an example, examine family histories to determine what relationship, if any, that history may have to physical and psychological attributes of a crewmember. Attempt to screen out a crewmember such as the physician who recently had an emergency return from Antarctic with breast cancer.

C. Diagnostics

1. Physiologic
    a. Imaging
    b. Laboratory analysis (fluid, gas, tissue)
    c. Advanced physical diagnostics, better tools for physical exam - more than an "improved stethoscope"

2. Psychosocial
    a. Advanced diagnostics
    b. Interpretive analysis and situation assessment

D. Interventions

1. Physical
    a. Non-medical (blistered foot)
    b. Resuscitation
    c. Pharmacological
    d. Medical life support
    e. Surgical decisions

2. Psychosocial
    a. Non-medical
    b. Psychological pharmacology
    c. Behavioral modification
    d. End-of-life decisions
        Isolation, disposal, palliative care, and euthanasia

E. Scenarios (some that we thought of that should be addressed as examples)
1. Burn
2. Crush
3. Cancer
4. Obstructive kidney stone
5. Dental abscess

<u>Subgroup B.</u>

Rather than redefine high level medical requirements, we elected to redefine high level medical informatics requirements. We did start out our discussion much as Subgroup 2 did. Then we decided that we would focus on medical informatics, which should evolve in tomorrow’s discussion into specific things much as will be discussed by Subgroup 2. So our statement was that medical informatics must support prevention and monitoring, diagnosis and decision support, and intervention treatment. And you’ll see the rest of this came from Roger’s presentation early this morning that stated that the key elements of the medical informatics system must include user interfaces and displays, intelligence and automation smart systems, sensors and data acquisition systems, computer-based training and simulation, and communications infrastructure. So, we think we've encapsulated pretty much the medical requirements in this way that will lead to further discussions tomorrow.

Medical informatics must support prevention, monitoring, diagnosis, decision support, intervention, and treatment. The key elements of the medical informatics system must include user interfaces and displays, intelligence, automation, smart systems, sensors, data acquisition systems, computer based training, and simulation and communication infrastructure.

Subgroup C.

It is a fact that crews who are at a great distance from Earth such as those approaching Mars will not have real-time communications with mission controllers on Earth. They will be able to communicate, but there will be substantial time delays in communicating. Given this as a fact, the sub group notes that NASA must address autonomous crew operations and this includes being autonomous when it comes to medical care. The methods that Russia and the United States have proposed with regard to this differ, and these differences must be addressed. The sub group assumed that there would be at least one physician and possibly two assigned to a mission in which medical care would need to be more or less autonomous.

A. Assumptions

1. Crew should be considered autonomous even though they may communicate with Earth.
2. A member or members of the crew will be a physician, level of training required must be addressed.
3. Communications with the crew from Earth will be limited
4. Medical informatics technology will evolve and NASA must adapt as appropriate.

B. General Requirements

Knowledge, technologies, systems, and sufficient understanding of space physiology and space medicine clinical practice to support:

1. Diagnosis and treatment
2. Medical information
3. Medical education and training
4. Health maintenance and prevention

C. High Level Requirements: (Level 2)

1. Develop an adaptive, integrative medical care capability to address a emergent, acute, and chronic processes i.e., very smart medical machines.
2. Develop a comprehensive system for diagnosis that provides feedback autonomously.
3. Integrate information systems technology and smart system technology to enhance health care capability.
4. Develop, apply, and integrate biologically inspired technologies for health care.
5. Integrate virtual tools and environments to support autonomous crew operations.

The following are comments made by participants following the presentations of the subgroups:

We actually entertained the possibility that absent some kind of definition of what the mission scenario is, it might be very, very difficult to come up with meaningful high level requirements especially as they relate to interaction and required skill sets on board. In other words, what skill sets does your health care provider have to have versus what kind of capability do you have?

Another way to "slice this salami" sometimes is to talk about core competencies. Often in strategic planning, companies will stake out a vision and a core competency that allows them to exist against competition. Applying the business model of strategic planning to research and development or health sometimes gets away from that. Sometimes it's useful to come back to it because the idea of strategic planning assumes that there is competition for something, that there are not unlimited resources; therefore, decisions have to be made, compromises have to be made. Sometimes core competency, because it relates so closely to the mission, is a reasonable consideration

Another way out of that box is just to take a lesson from the situated cognition people, particularly early on, and realize that knowledge and skills are not just in people. They are a combination of the people and the machinery. Understand the knowledge and competence you want onboard. At a later time, decide how you want to slice the skills and knowledge between the machine and the human. Because the skills and knowledge may be distributed, they may be considered a combination of how the people and machines interact. You may put off how you split these until a later time and decide the competencies and skills you want in the machine as opposed to in the people.

One of the things that we discussed *ad nauseum* was that we don't know what the skill set of the physician or the machine is going to be twenty years from now or whenever an exploration mission may occur. So, rather than trying to define what the physician or the machine should do, we need to wait on the technology and use the International Space Station as a stepping stone in autonomous development of health care for the crewmembers. As technology catches up or moves ahead of the requirements, then that's put into the skills of the physicians who are going to fly. Just as the Station is a stepping stone for exploration technology, the Station should also be a stepping stone for the technology of the autonomous physician who will work on Mars or the Moon or wherever he or she happens to be.

Rather than trying to define particular skill sets or technology, we felt the grater issue is that the greater the distance – the further out – and therefore, the longer the return time, the longer the communication lag time will be. The greater the autonomy of the crew, the higher their skill set should be and the more that medical informatics and telemedicine, in whatever form, are needed for full support. The greater the distance of the crew from Mission Control, the higher the level of medical capability one should have.

Exercise 3: Approach and Future Developments (Craig Fischer, M.D., facilitator)

The subgroups were task to consider the approach(es) that might be employed to address vision and requirements.

<u>Subgroup A.</u>

A. Communications

1. Onboard a high bandwidth capability is necessary and elements should be independently capable. For example, imaging instruments should have independent storage, processing, and display.
2. Communications to a central repository using high bandwidth for "store and forward" capability.
3. Access to real-time data onboard.
4. As appropriate, use of wireless technology to handle data and communications onboard.

B. Sensors - integrate into distributed system - include the crewperson and embed sensors where possible.

1. Should be minimally invasive
    a. Imaging sensors (CT, MRI, DEXA, etc.).
    b. Ionizing radiation sensors required crewperson and space craft.
    c. Sensors to assess the contents of fluids and gases must be addressed.
    d. What sensors may serve the function of dental x-rays?
    e. Embedded
        Identification
        Physiologic parameters

C. Transmission

1. High bandwidth, 1.5 Mb/sec (T1) necessary for images and “store and forward”
2. Relay capability for communications block by sun, etc.

Communications delays and dropout may hamper exploration class missions. In some cases relay satellites may be employed to overcome part of this problem even when such missions are "behind the sun."

D. Analysis

1. Simulations/models
2. Adequate decision support
3. Protocol supervision
4. Education and mentoring
5. Virtual environments with haptic feedback

E. Treatments

1. Smart devices and products
2. Simulations
3. Decision support
4. Protocol supervision
5. Capability to manufacture special tools/equipment and medications
6. Robotic surgery
7. Crewmember isolation as required
8. Recreation and psychosocial support

Creative versus algorithmic care was discussed. A high level of skill will be required of health care providers on an exploration class mission. Creative use of onboard capabilities may be required, not blind adherence to a pre-established protocol. Requirements must address algorithmic and creative care. Health care on a space mission will likely require more than could be accomplished by one who follows a "cookbook."

<u>Subgroup B.</u>

Our group felt like it had just returned from a time warp where we at times were wandering for 40 days and 40 nights. I’m going to show you some snapshots of ideas and thought processes rather than a real organized plan. In his introduction Sam spoke about when the Space Station gets up and running there will be more autonomy, but also an increasing support structure or consultative network from various ground-based points. Ultimately, exploration class missions will have limited communication; therefore, autonomy is a necessity. That won't eliminate both Mission Control and Mars base wanting to maximize the communication and the information flow.

No matter how much the bandwidth improves, I doubt that we'll ever agree that the bandwidth is adequate and that we wouldn't want more. So, whatever the improvements in technology are, there will probably be a bandwidth issue.

Travel time and communication time will both be issues particularly as we go further out. Storage and payload are dependent on the amount of space available. Shelf life may be very limited, either for instrumentation, pharmaceuticals, or whatever you're bringing on. Also the knowledge base is an issue as far as limitations and concerns of the crew and the ability to uplink. Storage, shelf life, and knowledge base are issues that have serious limitations.

The population that we're dealing with may be an issue. As facilitator for a large telemedicine program, it's very common to hear people say, "Oh, we want to do telemedicine." That's great, but what really are your medical needs, your health care needs? Looking at this population, it's a healthy pre-screened population.

There are occupational issues that relate to space environment exposures.

What is normal space physiology? We don't fully understand space physiology, how then are we to fully understand medical diagnosis and intervention?

Pharmaceuticals. We know we're going to need pharmaceuticals or a drug store. We have a limited packing or limited suitcase size, so what are the drugs we're going to want to bring, the shelf life, and quantity? How long do we pack for?

Procedural. There's always been an issue of lacerations, trauma, etc. You know CT is great and MRI would be wonderful, but at this point in time, we don't have the capability to fly these items in space. Routine, the monitoring or health maintenance or comparison to the ground base baseline of health, and emergent situations and diagnostic problems should be addressed.

Communication security is an issue.

The following is not a complete approach or a plan, but is rather a snapshot of our thought process on this subject.

A. Limitations and Concerns

1. Bandwidth issues
2. Storage - competition with other needs and payload
3. Shelf life
4. Knowledge base

5. Travel time and remoteness
6. Communication time and access

B. Population

1. Healthy and prescreened
2. Occupational medicine support
    a. Space environment
    b. Space flight norms for physiological parameters
    c. Exploration and EVA risks
3. Emergent and trauma
4. Unexpected illness

C. Components

1. Ground-based
2. International Space Station
3. Exploration

D. Mars

1. Pharmaceuticals
    a. Limited selection
    b. Shelf life
    c. Amount limited
2. Procedural
    a. Lacerating trauma
    b. Minor operations
    c. Major surgery
3. Diagnostic
    a. CT - MRI - etc.
    b. Routine
    c. Monitoring
    d. Emergent
    e. Communications
    f. Resident database - virtual reality
    g. Security
    h. Mentoring
    i. Communications, ground-to-ground, ground-to-space, space-to-space
    j. Noninvasive and invasive sensors
    k. Smart sensors

Subgroup C.

A comprehensive needs assessment is required. NASA must address matters just as if it were planning to develop a trauma center. Look at predictable problems and at some unexpected problems with various scenarios to develop policies and procedures. Communications with ground support is a high priority and must be adequate. Address trauma and other difficult issues.

Scenarios should include difficult cases such as those that require total parenteral nutrition or IV fluids for survival. What would be done if long term support were required? NASA should address the application of ultrasound as a diagnostic tool. Due to communications difficulties, “store and forward” capability is essential. What about real-time, or as close to real-time communications as possible and what role will be assigned to smart systems? In general NASA should learn to expedite, adapt, integrate, and validate systems. This activity should be based on performance requirements. Do we push the technologies or do we wait and pull the technologies that are developing? The answer is we must use both approaches to rapidly incorporate new technologies.

Exercise 4: Advice to NASA (Roger Billica, M.D., facilitator)

Each subgroup was tasked to make its final recommendations: "What does NASA need to address with regard to medical informatics and telemedicine for space flight?"

Subgroup A.

The question was: “What would you like NASA to hear from your group?” We have a couple of different level issues. There is clearly no consensus from the past day that there was any intent to send a physician on a Mars mission or on any exploration class mission. So, that’s number one on our list, not in terms of priority, but it just came up, that there should be a physician on exploration class missions.

Number two and three are more motherhood and apple pie types of recommendations, that there should be integration and collaboration. The integration clearly needs to be both vertical and horizontal. There are clearly more requirements for integration between engineering and medicine at NASA and it’s also true in the systems sense that there needs to be better integration. The collaboration issue needs to be accomplished with the medical community, to investigate what’s available, to see what the medical community thinks about things. There needs to be internal collaboration within different parts of NASA. There needs to be another collaboration outside NASA with DOD, NIH, other groups, Federal and private, in terms of the collaboration suggestion. It’s important to note here to include the JSC space medicine team whenever there are medical issues that are discussed at any level and collaborated within NASA, out of NASA, with other agencies.

Number four, which is to make medical informatics the architecture of space medicine, we feel is our biggest contribution. What we're saying is that medical informatics should be the road map for every part of medical care, all the parts of medical care of our astronauts, again as medical informatics. This is the overused phrase of the paradigm shift, and it doesn't just apply to space medicine, but to medicine all around the world. Medical informatics will drive the future development of medicine, so NASA has the opportunity to be in the forefront of that and to take that model and use it to drive further developments. Ron Merrell will discuss this in further detail in his closing comments.

Number five, operational medicine needs to drive biomedical science R&D. I think that speaks for itself. I don't need to say more about it.

Number six is an adequate budget to accomplish the mission. Ideally, the adequate budget would also include the input and some determination of how to spend that budget based on space medicine team input.

Number seven is to form partnerships. Number seven integrates with number five; operational medicine needs to drive biomedical science R&D. It needs to be a partnership. It's clearly not a one-way street. In a partnership, biomedical science needs to be held accountable to deliver mission relevant products to the operational medical team. Again, this isn't intended as a one-way relationship. It needs to work both ways, and that's well recognized by our group. It just felt important to say that.

<u>Subgroup B.</u>

I think there's an awful lot of overlap with what was just said and a lot of like-mindedness. We focused on beginning with a cost risk analysis at the very beginning and making certain that that cost and risk analysis was based on NASA and the peer review-generated requirements, so that we really understood the problem before we got started. We focused on this being evident in space. We would use this cost risk analysis at any point in time to generate a set of requirements for medical capabilities. We took Dave's two-dimensional probability and severity and added on to that a third dimension, which is resources or cost. We felt that any medical problem in the entire gamut of disease, disease prevention, and wellness could be put into a cube. Any medical condition at all could be put into a cube, and that cube would be based on current technologies. It would be obvious to eliminate conditions that are low probability, low severity, and high cost. At any point in time, technology might change, which would allow us a lower cost, lower resources solution, and we might be able to include that particular disease process. We used, for example, myocardial infarction and thrombolysis. We might decide that the probability was very low, the severity would be very high, and the resources and cost would be prohibitively high to deal with that problem with current technologies. When the resources and costs become low, we might revisit that and deal with it later.

We wanted to send a message to NASA to focus on these three bullets:

1. Interoperability
2. Integration
3. Standards

We felt that perhaps the role of NASA in this would be to take all the disparate medical technologies and capabilities and create a standard or a set of standards that would allow us to bring Mars to Main Street now so that we don't have to wait till we've actually sent something up into outer space. We can start to use these integration standards to bring things back to Main Street now. That would include using these technologies in the near term for clinical trials and for other clinical applications. Here on Earth it might be humanitarian, it might be rural health, etc.

We wanted to send a message to shift the focus from telemedicine. We as a group generally agreed that there's really no such thing as "telemedicine." We wanted to shift that to the practice of medicine using advanced technologies, for example, telecommunications, decision support, computer-aided diagnosis, etc., etc. And we wanted to state that so emphatically that we added, "Darn it."

Then we wanted to look at the human-machine interface, and the possibility of having adaptive kits of control between the human and the machine that would occur on a dynamic basis over time to make certain that the interface was reconfigurable over time according to the needs of the crew.

We realized that of all the medical probabilities and possibilities that the most probable medical problem would be not physical but psychosocial, and we talked about using technologies to provide more psychosocial support. That might include things like recreation, perhaps virtual reality games, things like that, conflict resolution, the ability to use technology to help with group dynamics, and even issues such as privacy. Perhaps we don't have an awful lot of "hiding" space, but we could potentially use virtual reality to create a sense of privacy and aloneness. And I personally would love to see a holodeck if I were going up there, but that might be another issue.

<u>Subgroup C.</u>

We talked about a lot of different things in the group and generated another spirited discussion. I like this term that I think Ron Merrell used so well "a community of scholars," and the fact that this is the second really large meeting we've had to look at strategic directions and telemedicine within the Agency and specifically for space flight.

I'm really glad we finally got to do this. We've been doing meetings of one form or another about medical operations, about environmental medicine, about medical monitoring, all kinds of different meetings, but to actually have one focused on this technology is really great.

I think the number one thing is to develop partnerships. NASA can't do a lot of this stuff by itself, nor should it because we may be able to use a lot of technology developed elsewhere, so why go out and reinvent the wheel? So, develop these partnerships with industry, academia, and other governments. The purpose, of course, is to leverage the technology, information, and science, as well as the way we practice medicine. I know that there's an effort to look at what we're doing and other groups have come together to give us advice at least during the last ten years that I've been involved. And we also benefit from industrial partners. That's what a commercial space center does. If we invest in a technology or some kind of capability, we get the opportunity to apply it to space flight. If it meets a need, the company can then spin it off as a technology or a commercial product. So there's a lot of interest from the industrial partners.

We need to integrate the process and there needs to be a commitment to integrate the process. We have funded the telemedicine instrumentation pack for the last seven or eight years. If we're going to move forward with something like that, it needs to be integrated, not only into medical operations, but also into the system so that the engineering community in this Agency or this Center knows what we need and knows the requirements. We also need to develop a process on how to get to that next point. I've heard from people both here and at Headquarters talking about going from medical kits to virtual surgery. Well, where's the middle piece? We're making a quantum leap. There's got to be a process that takes us through that.

We need to train space medicine practitioners in information technology, telemedicine, medical informatics, whatever term you use. They have to be aware of those technologies and how they can be integrated in addressing and practicing space medicine both on the ground and in-flight.

Test beds are a very important aspect. We've done a lot of work with the KC-135. We've done things with Indian reservations, with foreign countries. It's very important that we tell the Space Station community and the Space Station program office that we intend to use the International Space Station as a test bed to test telemedicine technology and medical informatics technologies in the near future.

Needs assessment is a very, very important aspect – we need to develop the best system to address medical care in space. It's not something to be taken lightly. We need to find out what the true needs are. They may be based on different kinds of illness or injury. I know Roger and his group have put together a tremendous database on what has happened in space – both in the US and Russian programs. We need to take a look at that and that should be used to temper our approach.

A lot of what we've talked about are requirements, but I think Sam's charge to us was to focus on strategy. NASA Headquarters develops medical policy and everything below that is NASA center responsibility. JSC has lower levels of requirements: Level I (Program), Level II (a little more detail), Level III (a lot more detail). I think a lot of what we have talked about here is in the middle of Level I, Level II.

Validation is a requirement. Validation of the hardware and making sure that those things work through testing and verification are required. Validating the actual docs who are going to be space medicine providers is also necessary. I think Sam and the international partners have done a great job of that.

We've come up with a ballpark schedule. Somehow the year 2008 is a magical number for a go/no go decision on going to Mars. I don't know why 2008 is so spectacular, but there's a lot of time between now and then to use the Space Station as our test bed and actually look at collaborative computing, collaborative environments, the infrastructure to support that, integration of information technology, biosensors, and smart systems. We have been working on the smart systems with the Defense Advanced Research Projects Agency (DARPA), both when we were at the commercial space center at Yale and now down at the Medical College of Virginia looking at smart clothing, sensors you add to T-shirts. One of the things they've been working on at JSC is the sock that has the pressure points to look at how those sensors might be useful in health care. We looked at having these things available in 2000-2002. The budget that NASA submits to OMB now goes to 2003. So in a few months if we really want to go forward with new technology, we need to get those dollars, we need to go forward with new requests. I can almost guarantee it's not going to go anywhere, but as a community, we ought to go forward to send that message.

Autonomous systems. I'm not sure what autonomous systems include, but they're thinking systems that can help physicians to make decisions. They should be available in this 2008 to 2011 time period.

Outreach. NASA has a tremendous outreach capability. Of course, we reach students from K-12 and graduate programs as well.

Collaborative environments. This is a really aspect in the Administrator's view, especially with aeronautics. We talk about distributive systems with our European partners, our Japanese partners, our Canadian partners, and Russian partners. I'm sure that Brazil and Korea and all those other countries will become larger participants in the years to come and will be connected in some way as well.

I think one of our biggest challenges and absolutely mandatory requirements is to have adequate communication systems. We can't pay lip service to it. If a medical event occurs in space, will we have the communications to take care of it? As someone who sat on a console for years as a flight surgeon, that may not necessarily be true. I know that NASA and especially the Administrator's safety approach and some of the stuff that Arnauld is doing at Headquarters really focus on space medicine. I would add non-monetarily by the way, but at least by trying to push that, he's trying to make that a number one priority. Again, we need to go forward and say, "This is our requirement." I don't know if it's T-1 or OC192. There's a wide range there, but we need to go forward and tell them that's what we need and we're not going to live without it.

I think the medical hardware needs to integrate with all platforms. You can't develop a system like a fax machine in the 1970's. Two different fax machines wouldn't talk to one another. We're going to have software, different devices. There're all going to have to be interoperable, interchangeable, and all sort of work on the same platform. The other very important part is this. When I first got a group together in 1996, there was very little communication between the pockets of what would be considered telemedicine. And that's still the way it is today. There's more communication, but there's still a lot of technology that's within other NASA commercial space centers (and there's 16 of them) and the NASA centers themselves. There's a lot of telemedicine activity at Langley and at Lewis, but they're not represented at this meeting. That doesn't mean our thoughts aren't with them on this. We want to make sure that we all talk to each other as a community of scholars, and get this message out. What do we have available as an Agency to share with TATRC, to share with NIH, or to share with the National Library, and so on?

Standards of technology. If we're going to do something in this country and we're going to communicate with our European partners, we need to be similar in capability, similar in standards. Of course, we talked a lot about interoperability. There's a lot of variance from a management point of view. We need to have more cooperation among the Centers and the other Agencies about what we're doing. Part of that is, obviously, participating in meetings and attending scientific seminars. But we need to make sure that we get rid of those barriers and move forward. The engineering community may say, "We don't have this much crew time for training, or we have only this much time for communication." Some of those issues we may not be able to circumvent, but we need to be aware of them in terms of how we might change them.

Be aware of the needs for medical operations. I know I've said this time and time again. The reason our Agency does telemedicine is not because of outreach or because we want to do things with other countries; it's because we want to make sure that whatever we do technology-wise is driven by the medical operations needs. That's what Roger and his group of flight surgeons need to take care of the astronauts. That's at all levels. When our Administrator goes out and talks about telemedicine, we need to make sure he knows what we're doing as an Agency, not just what we did in Armenia, or what we did on the TIP, or whatever the case may be. We need to make sure we get that message all the way to the top.

The outcome? What's the next plan? What's the next step? What's the risk and the consequence if we don't have a system in place to address these issues?

Concluding Participant Discussion

I'd like for NASA to come up with a list of medical occurrences that are based on the population you're dealing with.

Sam Pool: We're doing that.

And then, if we had that list, we could categorize those boxes. We could guess it would be very helpful in determining now what kind of program could be developed, or if there are projects to be augmented, or new things that you may or may not be aware of. Do you want to leave the door open to augment that kind of development?

The advantage when you draw the line through the cube that shows what you're going to support and what you're not, is that you can make a very clear case in terms of medical support for the risks and consequences. You can make a clear case to Headquarters, for example, that a lot of these other risks…

Pool: What we know and what we don't know about space medicine.

It was also brought up and discussed. It seems the perception of reality is that … if you lay out the medical occurrences and prioritize them and then deal with the reality of the payload constraints, communications, the budget, then respond and say if you are setting the bar here for payloads or for budget, which of these medical occurrences do you want to put in that we are not capable of addressing? And that empowers them to raise the bar or whatever.

Pool: We've not completed that, but we're part way along the way. Roger has looked at submarine data, Antarctic data, and data from other extreme environments and analyzed the types of problems experienced. Perhaps more appropriate, we're looking retrospectively at what happens to astronauts on the ground medically. That's pretty informative. I think the workshops that are coming up in the near future to address the development of space medicine algorithms are important. We plan to start these workshops by sharing with the participants what we know about incidence in our community on the ground and in space flight. That should make the next year's conference to consider medical informatics much more relevant.

One comment about process. I want to acknowledge NASA for the outreach to the community of experts for assistance in your mission planning. I think this is really a good start. But I would recommend, based on this start, if you want to continue with that kind of outreach that you give some attention to the process of expert panel methodology that would perhaps better prepare us to talk to you and achieve your goals and in the process ultimately be more efficient and productive. I know that's not easy to come by. I've thought a lot about how to do it. We've struggled with the possibility of doing this for the Army and there are a lot of pitfalls. So, one great acknowledgment for the start and a recommendation for putting some structure inside the process

Pool: I think you're right on target. The process of convening groups that are fairly divergent in some respects, but very talented in many respects, and then bringing everybody up to speed so that we know how to work together is a time-consuming and somewhat delicate process. I'm suggesting that this be a continual process, in other words, that we have such a meeting annually. The structure for the next annual meeting will be different from this one because we've come to understand and know each other better. I plan to draft a report from this meeting and I hope that that can be done rather quickly. I plan to share the draft report with you via e-mail. I'd like very much for you to take a few minutes and comment on the parts of it that are of interest to you or that you think are a little off base or whatever. And then in a few weeks I plan to issue a final report to the committee. I plan to assimilate what you've said and put it in some sort of order and maybe make some additional comments of my own. This will be part of the dialog and hopefully will be a step along the way to creating a truly expert NASA panel in the discipline of medical informatics for space medicine. I want to thank you for participating on such short notice. I'm going to give Ron Merrell the last words. When he's finished, we're finished. I really do appreciate your responding on such short order to our request to come to a meeting like this.

Volker Damann: What is the outcome of the recommendations that we've made? Is this the final step? Where does the report go?

Pool: The information from this workshop along with other information that we have will be used to create a strategic plan for NASA to proceed with its medical informatics and telemedicine efforts. Perhaps the ISS international partners may wish to contribute once we get a little bit further along with planning. OK, thank you. I appreciate your participation, and I'm going to let Dr. Merrell have the last word and make the concluding remarks.

Summary and Conclusion

It is always a pleasure to be this close to Space Medicine's home base. There are people here who have the courage to presume that they're going to provide health care for people who are many miles away, traveling very fast in fragile engineering wonders.

In terms of process, Jay Sanders, Chuck Doarn, and I have had the task of reworking NASA's telemedicine strategic plan. Over the last day I've taken the report that came from the September telemedicine meeting which Dr. Roger Billica nicely summarized and plan to fold that information into the HQ strategic plan. The last thing you want is to have something important somehow not covered. The NASA strategic plan for telemedicine needs to be an umbrella policy statement. You do not want to have something that's really hot come along and not get covered. I think we will take Dr. Sam Pool's summary of our day and a half here, which has been rich in important observations and include these thoughts in the NASA strategic plan. The strategic plan is a very important document for budgeting and project planing.

If I were to pick one important thing that happened in the last two days, it is the emergence of the concept that Medical Informatics is to be the architecture of medical practice in space. I've never quite thought of medical practice in that way before. In fact Medical Informatics may be the architecture for the practice of medicine on Earth in the future. We were always thinking about ways to apply telemedicine on Earth, or to fly a telemedicine capability in space, or to use new methods of telecommunications in medical practice. In fact, we're educating medical students to practice medicine in a different way; we're preparing future physicians to be information managers. It's impossible to arm physicians with all of the pertinent information required so they can be walking around as "intelligence machines" that can process patient complaints and come up with the best answer for all their patients. That model of health care, the ambulant health care model, is dead, and should go away quickly. There's no way to practice medicine in a conscionable way without being fully linked to the mass of information that subtends, or should subtend, evidence based medical practice.

I think the term "telemedicine" is too confining I'm just as happy to talk about medical informatics and one of the recommendations I will make to NASA is that we not have a strategic plan for telemedicine but strategic plan for medical informatics. In selecting medical informatics, at least have terms that have definitions that are generally acceptable. Informatics is applied to the science of information. Medicine is applied as the profession or the process that either restores or retains the state of health. Health as a rule is defined as a state of mental and physical well being. I think that if we stick to fairly strict Oxford dictionary rules, medical informatics is comfortable to me. And to say that it's going to be in the architecture, the context, for medical practice on Earth is certain to anticipate that medical informatics will be the context for health care in space. If one starts with that statement then I think its fair to say that space medicine is not prepared anymore than the rest of health care on this planet to practice in the context of medical informatics. Therefore, research that will be going on in the next number of years must move toward that fairly obvious objective; otherwise medical informatics will certainly overwhelm health care practices and space medicine might not be prepared.

I like the vision statements. I believe that you could have a four sentence vision statement that would be fairly encompassing. Group three had a very nice statement. "NASA will provide quality health care for our astronauts through the integration of medical information technologies." Stop here? But I sort of like group two's, "NASA will acquire, develop, and apply medical informatics to support space medical practices in space, optimally independent of distance and time." I like the idea that it should be a collaborative effort and reflects the evolution of health care for NASA missions. I really thought group one caught it when they said, "The desired outcomes will be determined by risk assessment of the overall mission and oriented toward maximizing mission success." I would add the phrase “through Continuous Quality Improvement (CQI).”

I think that other products that we may want to utilize or help summarize this meeting would include the lists. Group one had a wonderful list of technologies that I think can be cataloged and I didn't hear anybody objecting to that. It was a fine list. It would seem to me that the comments that have been forthcoming from the three groups in this last session could be melded into a set of bullets that would inform and arm. It would be a treat to come back on a recurring basis. It is important for NASA to establish the telemedicine advisory group that was recommended in the September meeting. There is the Aerospace Medicine and Occupational Health Subcommittee; however, there's nothing like the panel that was proposed at the September meeting and I think that that would be a fine recommendation or outcome from these two meetings over the last couple of months.

It’s exciting to think about the future and NASA always forces you to do that -- to challenge you with problems that you just never thought of in your own practice, in your own science, in your own lab, or in your own department. I'd like to thank Sam, Craig, Dave, Dave, and Roger for their being forthcoming and generous with time and letting us see again some of the great things that are happening at NASA. I thank you for the chance of our participating, and we look forward to seeing the capsilized version of what we've done and to seeing positive outcomes in the years to come.

Ronald Merrell, M.D.

Appendices

Appendix A – Meeting Agenda

NASA Telemedicine Developments
For Space Flight Application
Meeting Agenda
Meeting Place
Nassau Bay HILTON Hotel

November 9, 1999 Day 1

7:45 AM	Welcome; Thoughts about Telemedicine; Charge to the working group	Dave Williams
8:30 AM	Introductions & Agenda	Sam Pool
8:40 AM	NASA Telemedicine Developments For Space Flight	Roger Billica
9:30 AM	MITAC Telemedicine Efforts	Ron Merrell Jay Sanders Chuck Doarn
10:00 AM	Break	
10:15 AM	NSBRI	Vincent Pisacane
10:40 AM	JPL	V. Sarohia
11:00 AM	Review of Interest and Developments International Partners	Japan, K. Shimada ESA, V. Damann
11:30 AM	DOD Developments	Michael Freckleton
12:00 PM	Lunch	
1:00 PM	Communications & ISS	TBD
1:30 PM	Reality Check	Roger Billica
1:45 PM	ARC & Stanford	Muriel Ross
2:00 PM	Break	
2:15 PM	Develop Vision for Telemedicine Applications in Space Flight	Group Activity Sam Pool

3:15 PM	Define Developments Required to Support Vision, Short & Long Term: Including Advanced Dx & Rx, “keyhole” – Minimally Invasive Surgery	Group Activity James Logan
5:00 PM	End Session	

November 10, 1999		Day 2
7:30 AM	Summary of Vision & Required Developments	Sam Pool
7:45 AM	Develop Strategy For Approach To Future Developments, Short & Long Term	Group Activity Craig Fischer
9:00 AM	Break	
9:15 AM	Roles and Responsibilities	Group Activity David Dawson
10:30 AM	Schedule & Facilities Requirements	Group Activity Craig Fischer
11:45 AM	Summary of Group Recommendations	Ronald Merrell
12:00 PM	End Meeting	

Appendix B -- Participants

Medical Informatics and Telemedicine for Space Flight
Strategic Planning Workshop
November 9-10, 1999
Houston, Texas

Jake G. Angelo
University of Texas Medical Branch

Dave Balch M.A.
East Carolina University School of Medicine

Michael Barratt M.D.
NASA Johnson Space Center

William S. Barry M.D., MPH
NASA Kennedy Space Center

Rashid L. Bashshur Ph.D.
University of Michigan Health System

Roger D. Billica M.D.
NASA Johnson Space Center

Genie Bopp
Wyle Laboratories
Medical Operations

Oscar W. Boultinghouse M.D.
University of Texas Medical Branch

Timothy J. Broderick M.D.
Medical College of Virginia
Asst. Prof. Of Surgery

Donald J. Butler
Wyle Laboratories
Advanced Projects, Medical Operations

Jonathan B. Clark M.D.
NASA Johnson Space Center

Richard L. Craft M.S.
Sandia National Laboratories

Volker R. Damann M.D.
European Space Agency European Astronaut Center

Jeffrey R. Davis M.D., M.S.
University of Texas Medical Branch
Director, Preventive Occupational &
Environmental Medicine

David L. Dawson M.D.
NASA Johnson Space Center

Charles R. Doarn MBA
Virginia Commonwealth University
Executive Director
Medical Informatics and Technology
Applications Consortium

Charles H. Evans, Jr. M.D., Ph.D.
National Academy of Sciences, Institute of Medicine

Earl W. Ferguson M.D.
Southern Sierra Medical Clinic

Craig Fischer M.D.
NASA Johnson Space Center

Michael W. Freckleton M.D.
Wilford Hall Medical Center
Department of Radiology

Christoph R. Kaufmann M.D., M.P.H.
Uniformed Services University of the Health Sciences
Chief, Division of Surgery for Trauma
Department of Surgery

Andrew W. Kirkpatrick M.D.
Vancouver Hospital & Health Sciences Centre
Assistant Director, Trauma Services

Corinna (Cori) E. Lathan Ph.D.
The Catholic University of America
Department of Biomedical Engineering

James S. Logan M.D., M.S.
JSC/Kelsey-Seybold

Vernon McDonald Ph.D.
Wyle Life Sciences
Medical Operations – Advanced Projects

Norman E. McSwain, Jr. M.D.
Tulane University School of Medicine
Department of Surgery SL22

Ronald C. Merrell M.D.
Medical College of Virginia
Chairman, Department of Surgery and General Director, MITAC

Vincent L. Pisacane Ph.D.
Johns Hopkins University Applied Physics Laboratory
Asst. Director for Biomedical Programs

Sam L. Pool M.D.
NASA Johnson Space Center
Assistant Director for Space Medicine

Muriel Ross Ph.D.
University of New Mexico Health Sciences Center
Telemedicine Unit

Jay H. Sanders M.D.
The Global Telemedicine Group
Scientific Director, MITAC

V. Sarohia Ph.D.
NASA Jet Propulsion Laboratory

G. Rufus Sessions Ph.D.
Telemedicine and Advanced Technology Research Center (TATRC)
U.S. Army Medical Research and Materiel Command (MCMR-AT)

Kaz Shimada M.D.
JAMSS

Scott C. Simmons M.S.
Wyle Life Sciences
Supervisor, Advanced Projects Section

Jack W. Smith M.D., Ph.D.
University of Texas-Houston HSC
Professor and Chairman, Health Informatics
School of Allied Health Sciences

Don Stilwell
NASA Johnson Space Center

Steven F. Viegas M.D.
University of Texas Medical Branch
Professor and Chief, Division of Hand Surgery
Department of Orthopaedic Surgery

CW Vowell
JAMSS America
Senior Engineer

David R. Williams M.D.
NASA Johnson Space Center
Director, Space and Life Sciences

Appendix C -- Organizations Represented

East Carolina University School of Medicine
European Space Agency European Astronaut Center
Institute of Medicine, National Academy of Sciences
Japan Manned Space Systems America, Inc.
Johns Hopkins University Applied Physics Laboratory
Kelsey-Seybold
Medical College of Virginia, Virginia Commonwealth University
National Aeronautics & Space Administration/ Jet Propulsion Laboratory
National Aeronautics & Space Administration/ Johnson Space Center
National Aeronautics & Space Administration/ Kennedy Space Center
Sandia National Laboratories
Southern Sierra Medical Clinic
The Catholic University of America
The Global Telemedicine Group
Tulane University School of Medicine
Uniformed Services University of the Health Sciences
Telemedicine and Advanced Technology Research Center (TATRC), U.S. Army Medical Research and Materiel Command
University of Michigan Health System
University of New Mexico Health Sciences Center
University of Texas-Houston Health Science Center
University of Texas Medical Branch
Vancouver Hospital & Health Sciences Centre
Wilford Hall Medical Center
Wyle Laboratories